2.3 Impulse

Figure B2.7: Roadside barriers are designed to reduce injury during collisions.

Little did Sir Isaac Newton know that his laws of motion would eventually become an important link between science and the technology of the design and construction of major roadways in Alberta.

Figure B2.8: Sir Isaac Newton (1642–1727)

The technologies of safety features, such as roadside barriers, have been incorporated into the construction of highways and other major roadways. The intent of roadside barriers is to prevent vehicles from swerving off the highway. However, if this is their only purpose, the most appropriate design would be the sturdiest—the concrete barrier. Why, then, are other designs used? What are the links between the laws of motion and the technology of roadside barriers?

The answers to these questions can be found in the "Changes in Momentum" investigation you completed on pages 248 and 249. In the investigation, the change in the momentum of the marble was the same in each case because it had the same initial velocity and it was forced to stop each time. All of this occurred because a stopping force acted over a time interval. This could be accomplished by a larger force acting over a smaller time interval or a smaller force acting over a larger time interval. You can see how the change in momentum equals the product of force and the time interval by rearranging Newton's second law.

$$\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

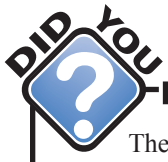
$$\vec{F}\Delta t = \Delta \vec{p}$$

Whether you stop a marble with a foam cup or stop a vehicle with a roadside barrier, the combination of a force acting over a time interval plays the essential role. That is why the product of the force and the time interval during which the force acts is given a special name—**impulse**.

$$\text{impulse} = \vec{F}\Delta t$$

Units: N·s N s

impulse: the product of the net force applied to an object and the time interval during which the force acts



The unit for impulse is N·s, which is the same as the unit for momentum, kg·m/s.

$$\text{N}\cdot\text{s} = \left(\text{kg}\cdot\text{m/s}^2\right)(\text{s})$$
$$= \text{kg}\cdot\text{m/s}$$

Impulse is a different kind of quantity because it does not have its own symbol. Instead, impulse is either represented by the word *impulse* or the variables $\vec{F}\Delta t$. This helps remind you that many combinations of a force acting over a time interval can provide a specific amount of impulse.

When it comes to stopping a vehicle with a roadside barrier, some combinations of the force and time interval are less damaging to the vehicle and to the occupants than others. How is the notion of impulse used to enhance transportation safety? Can these ideas be used to improve the protective abilities of sports equipment? In this lesson you'll explore the various ways of supplying an impulse by using different combinations of the force and time interval.

Example Problem 2.6

A raw egg drops to the floor. If the floor exerts a force of 9.0 N over a time interval of 0.030 s, determine the impulse required to change the egg's momentum.

Solution

Let down be the negative direction and up be the positive direction. Because the force on the egg opposes its downward motion, the force is directed up and is, therefore, positive.

$\vec{F} = 9.0\ \text{N}\ [\text{up}]$
$= +9.0\ \text{N}$
$\Delta t = 0.030\ \text{s}$
$\text{impulse} = ?$

$\text{impulse} = \vec{F}\Delta t$
$= (+9.0\ \text{N})(0.030\ \text{s})$
$= +0.27\ \text{N}\cdot\text{s}$

The impulse required to change the egg's momentum is 0.27 N·s[up].

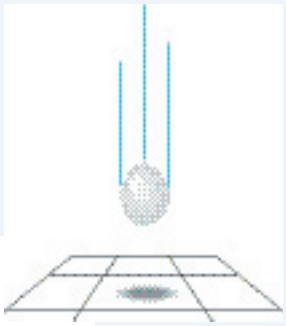
Example Problem 2.7

A raw egg with a mass of 0.065 kg falls to the floor. At the moment the egg strikes the floor, it is travelling 4.2 m/s. Assuming that the final velocity of the egg is zero after impact, determine the impulse required to change the momentum of the egg.

Solution

Let down be the negative direction and up be the positive direction.

$m = 0.065\ \text{kg}$
$\vec{v}_i = 4.2\ \text{m/s}\ [\text{down}]$
$= -4.2\ \text{m/s}$
$\vec{v}_f = 0$
$\text{impulse} = ?$



$\text{impulse} = \vec{F}\Delta t$
$= \Delta\vec{p}$
$= \vec{p}_f - \vec{p}_i$
$= m\vec{v}_f - m\vec{v}_i \quad \leftarrow \vec{v}_f = 0$
$= -m\vec{v}_i$
$= -(0.065\ \text{kg})(-4.2\ \text{m/s})$
$= +0.27\ \text{kg}\cdot\text{m/s}$
$= +0.27\ \text{N}\cdot\text{s}$

The impulse required to change the momentum of the egg is 0.27 N·s[up].

Practice

9. A hockey puck strikes a goalie's mask. The time interval of the impact with the mask is 0.012 s, during which the mask exerts a force of 400 N to change the momentum of the puck. Determine the impulse provided by the mask on the puck.
10. A truck collides with a concrete barrier. The time interval of the impact with the barrier is 0.050 s, and the barrier exerts a force of 2.2×10^6 N. Calculate the impulse provided by the barrier.
11. A 0.17-kg hockey puck travelling 28 m/s strikes a goalie's mask and comes to rest. Determine the impulse provided by the mask on the puck.
12. A 4000-kg truck travelling 28 m/s[W] collides with a concrete barrier and comes to rest. Calculate the impulse provided by the barrier on the truck.

A Larger Force or a Larger Time Interval

The concept of impulse can now be used to explain the design of crash barriers. If a vehicle travelling at highway speed is to be stopped by a crash barrier, its momentum must change from its pre-collision value to zero. In other words, the barrier must provide an impulse to change the momentum of the vehicle. As Figure B2.9 indicates, the impulse can be provided in more than one way.

In addition to keeping the vehicle on the road, crash barriers are designed to reduce injuries to the occupants and damage to the vehicle. It is best for the crash barrier to supply an impulse that keeps destructive forces as small as possible by allowing for a long time interval for the interaction. Water-filled barrels will stop a vehicle in a longer time interval, thus a smaller force will be exerted on the vehicle, resulting in less injury and damage. Concrete barriers will stop a vehicle in a shorter time interval, thus a larger force is exerted, resulting in more injury and damage.

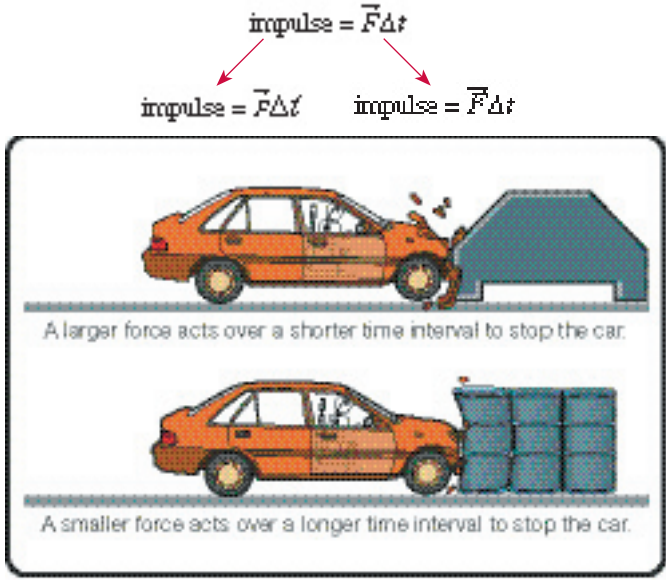

impulse = $\overline{F}\Delta t$
impulse = $\overline{F}\Delta t$
impulse = $\overline{F}\Delta t$
A larger force acts over a shorter time interval to stop the car.
A smaller force acts over a longer time interval to stop the car.

Figure B2.9: Two ways are shown for a barrier to provide an impulse to change the momentum of a vehicle.

Example Problem 2.8

Explain why it is less painful to catch a baseball with your bare hands if you let your hands "give" rather than catching the ball with rigid hands.

Solution

Because the change in the momentum of the baseball is the same in both cases, whether your hands "give" or are rigid, the impulse must be the same for each situation. When you let your hands "give," the time interval that the change in momentum occurs is larger, resulting in less force.

Practice

13. Explain why it is more effective to remove snow that is stuck to your boots by stomping your feet on a solid cement step rather than stomping your feet into a thick piece of carpet.
14. Why can you hit a baseball farther by using a hard, hickory bat rather than a hollow, plastic bat of the same mass?

Utilizing Technology

The Evolution of Safety Technologies

Purpose

You will explore the technological evolution of automobile safety.

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Automobile of the 1950s

Automobile of the 2000s

Procedure

1. The following table compares some of the automobile technology from the past with the automobile technology of today. Complete the table by explaining how the change in the technology has reduced injuries during collisions or interactions.

Automobile Technology of the Past	Automobile Technology of the Present	How the Change in Technology Helped Reduce Injury
metal front and rear bumpers welded solidly to the main frame of the automobile	large plastic bumpers attached through shock absorbers to a collapsible frame	
solid metal frame	collapsible frame with crumple zones	
metal dashboard, hard plastic steering wheel solidly attached to steering mechanisms of the automobile	padded dashboard and interior with a collapsible, shock-absorbing steering wheel	
no seat belts or air bags	seat belts and driver- and passenger-side air bags; often side-impact air bags	

Analysis

2. Seat belts have had a significant impact on the reduction of injuries associated with vehicle crashes. Use the Internet as a research tool to produce a point-form outline of the history of seat-belt use and how injuries have been reduced over the years since the introduction of seat belts.

2.3 Summary

Newton's second law of motion, in the form $\vec{F} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t}$, shows that the force applied on an object and the time interval over which the force acts are factors that determine the change in the momentum of an object. However, when the formula is rearranged into the form $\vec{F}\Delta t = \vec{p}_f - \vec{p}_i$, the product of the force applied, $\vec{F}$, and the time over which the force acts, D*t*, yields a physical quantity called impulse. The impulse provided to change the momentum of an object is the product of the net force applied to an object and the time interval during which the force acts. Since impulse is equal to the change in momentum, there are two ways to determine impulse: $\text{impulse} = \vec{F}\Delta t$ and $\text{impulse} = \vec{p}_f - \vec{p}_i$.

The impulse-change in momentum concept can be used to explain many technological safety advancements, not only in sports equipment and automobiles, but also in everyday life.

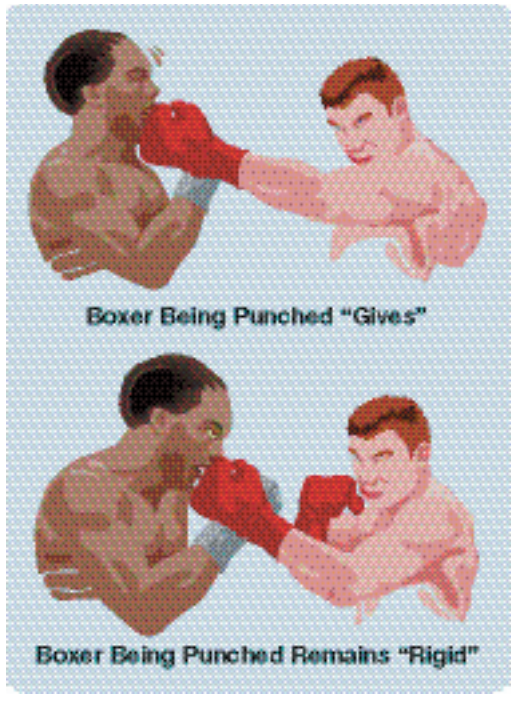
2.3 Questions

Knowledge

1. Explain the difference between momentum and impulse.
2. Describe the relationship between change in momentum and impulse.
3. State two equations for determining the impulse of an object.
4. Prove algebraically that the units for impulse are the same as the units for momentum.

Applying Concepts

5. Calculate the impulse provided in each of the following situations.
   - **a.** A moving billiard ball strikes the cushion of a billiard table. The cushion provides a force of 1.5 N on the billiard ball over a time of 0.020 s.
   - **b.** A ball of putty with a mass of 0.30 kg is thrown with a velocity of 2.1 m/s against a wall and sticks to the wall.
6. Determine the change in momentum in each of the situations described in question 5.
7. A soccer ball with a mass of 0.43 kg travels 14 m/s[E], strikes a goal post, and rebounds straight back with a velocity of 12 m/s[W]. Determine the
   - **a.** initial momentum of the ball
   - **b.** final momentum of the ball
   - **c.** change in the momentum of the ball
   - **d.** impulse provided by the goal post on the ball
8. Use the impulse-change in momentum concept to explain each of the following situations.
   - **a.** How do air bags reduce injury during a motor vehicle collision?
   - **b.** How does the foam lining in a bicycle helmet reduce injury?
9. Explain why the boxer being punched in the first illustration experiences less force than the boxer in the second illustration.



10. Compare the impulse provided by a wall on a
    - **a.** 0.20-kg rubber ball thrown with a velocity of 2.5 m/s at a wall and rebounding with a velocity of 2.0 m/s
    - **b.** 0.20-kg putty ball thrown at the same velocity at a wall and sticking to the wall
11. If the time interval of the impact with the wall was 0.012 s in both situations described in question 10, compare the force exerted by the wall on the rubber ball and the putty ball.
12. Identify five safety features on an automobile that reduce injury by using the concept of impulse-change in momentum.